PVCPIPE association

Utah State University
UTAH WATER RESEARCH LABORATORY

M.E. SIMPSON Co., Inc.

Hydraulic Testing of PVC Pipe

Laboratory and Field Tests Confirm Flow Coefficients

Hydraulic Testing of PVC Pipe: Laboratory and Field Tests Confirm Flow Coefficients

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Introduction

Historical Perspective

In North America most of the hydraulic research on PVC pipes was done in the 1960s and 1970s. These early tests established the following flow factors to be used for PVC pipe hydraulic design:

- Pressure pipe — Hazen Williams (HW) “C” factor = 150
- Nonpressure pipe — Manning’s “n” number = 0.009

Since friction-factor testing for PVC pipe in North America took place more than 50 years ago, the Uni-Bell PVC Pipe Association (PVCPA) decided to engage in a two-pronged test program: (1) laboratory testing of new pipe and (2) field testing of installed pipe. PVCPA contracted with Utah State University (USU) to:

- Perform hydraulic-flow testing at the University’s Utah Water Research Laboratory (UWRL)
- Oversee field testing of installed PVC pressure pipe

Research Program

Research goals were to:

- Measure hydraulic coefficients for pressure and nonpressure applications
- Determine if established coefficients were conservative compared to established values

Laboratory testing was performed at UWRL in Logan, UT, and overseen by Research Professor Steven Barfuss who is Associate Director of UWRL. Field testing was performed in West Valley City, UT, by M.E. Simpson Co., Inc., and witnessed by Research Professor Barfuss.

The results of both tests are summarized in Table 1. The procedures and testing undertaken are discussed in detail in the rest of this report. Test results for Darcy-Weisbach “f” are provided in Tables 1, 4, and 5, but are not discussed in the rest of this document.

TABLE 1: RESULTS OF LABORATORY AND HYDRAULIC FIELD TESTING ON PVC PIPE

Pipe Age	Pipe Size	Friction Factor Results
New	6"	HW “C” = 154 – 161 Manning’s “n“ = 0.0085 – 0.0070 Darcy “f“ = 0.012 – 0.017
New	12"	HW “C” = 150 – 157 Manning’s “n“ = 0.0094 – 0.0077 Darcy “f“ = 0.011 – 0.017
46 Years	8"	HW “C” = 164

LABORATORY TESTING

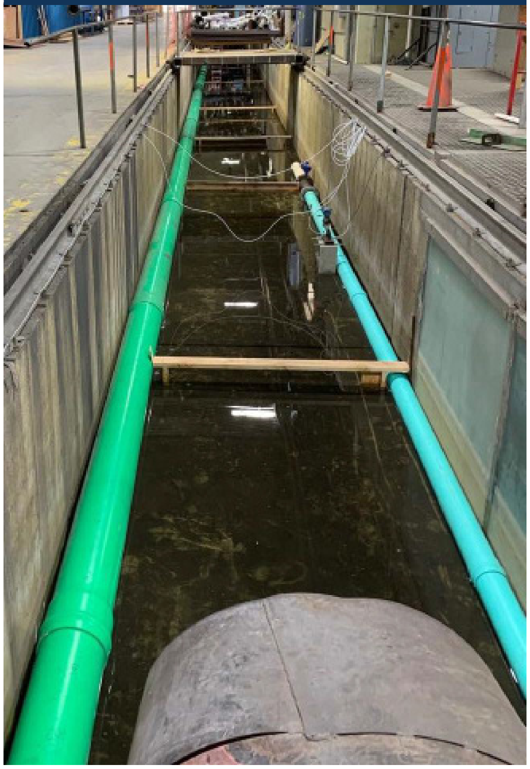
Introduction

Laboratory hydraulics testing was performed in March 2022 at the UWRL facility. The tests were run on 6- and 12-inch PVC pipe to determine three coefficients:

- Hazen-Williams "C"
- Darcy-Weisbach "f"
- Manning's "n"

To improve accuracy of measurements, minimum pipe length required was 200 times pipe inside diameter. Actual length for the 6-inch line was 111 feet (222 times ID) and for the 12-inch line was 220 feet (220 times ID). Figure 1 shows the test set-up for both pipes. To provide as much data as possible, tests were performed over a full range of flow rates under full operational pipe conditions for both pipe sizes.

FIGURE 1: 12-INCH AND 6-INCH TEST LINES (LOOKING DOWNSTREAM)



Process

Each test-section set-up included:

- A calibrated flow-meter installed in the upstream piping to accurately measure flow rates for each test run
- A control valve to adjust flow rates passing through the test pipe
- Pressure taps (each consisting of a hole through the wall of the pipe with a brass fitting) to make the tubing connections
- A pressure transmitter to make pressure-loss measurements between the upstream and downstream pressure taps
- Flexible tubing to connect each pressure tap to the high and low sides of the pressure transmitter for measurements of pressure differentials

After the test pipes were installed in the laboratory flume, wood braces and nylon straps were used to keep the pipes straight and to hold them in position when pressure was applied.

Flow meters were calibrated for accuracy immediately prior to the actual testing. For each test run, flow rate through the pipe and differential pressure along the length of the pipe were measured. Differential-pressure measurements were taken from the pressure taps that were installed in each PVC pipe at the upstream and downstream ends of each test pipe section.

Throughout each test, constant flow was maintained through the pipe length during the run period. Each averaging period took between 3 and 5 minutes, which was long enough to:

- Allow the flow rate and differential pressure to stabilize
- Record the actual flow rate through the flow meter
- Record the average pressure differential

Pipe Dimensions

Dimensions for 6-inch pipe are found in Table 2 and for 12-inch pipe in Table 3. Inside-diameter measurements were taken at the ends of the test sections (where the pressure taps were installed). Overall average ID is shown in each table and was used to calculate roughness coefficients.

TABLE 2: DIMENSIONS FOR 6-INCH PVC PIPE				
Section	**ID 1 (in)**	**ID 2 (in)**	**ID 3 (in)**	**Average ID (in)**
1	5.88	5.85	5.88	5.87
2	5.88	5.87	5.85	5.87
3	5.85	5.88	5.89	5.87
Overall Average ID (in)				5.87
Average Flow Area (in^2)				27.10
Average Flow Area (ft^2)				0.19

TABLE 3: DIMENSIONS FOR 12-INCH PVC PIPE				
Section	**ID 1 (in)**	**ID 2 (in)**	**ID 3 (in)**	**Average ID (in)**
1	11.69	11.65	11.65	11.66
2	11.63	11.68	11.65	11.65
3	11.60	11.68	11.68	11.65
Overall Average ID (in)				11.65
Average Flow Area (in^2)				107.00
Average Flow Area (ft^2)				0.74

Results

Test results for the friction coefficient tests are shown in Table 4 for 6-inch PVC pipe and in Table 5 for 12-inch pipe. Darcy “f,” Manning’s “n,” and Hazen-Williams “C” are listed in each table. Flow velocities were 2 feet per second and greater as shown. The coefficient results for these tests vary with increasing Reynolds number, which is consistent with the Moody Diagram and other theoretical calculations.

TABLE 4: TEST RESULTS FOR 6-INCH PVC PIPE									
Run No.	Flow Volume (cfs)	Flow Velocity (fps)	Inlet Reynolds Number	Friction Loss (ft of H_2O)	Friction Loss (psi)	Hydraulic Slope (ft/100 ft)	Darcy "f"	Hazen-Williams "C"	Manning's "n"
1	0.5	2.7	84,600	0.42	0.18	0.38	0.017	154	0.0085
2	0.8	4.2	133,000	0.95	0.41	0.85	0.015	157	0.0081
3	1.1	5.7	182,000	1.67	0.72	1.50	0.014	158	0.0078
4	1.4	7.3	230,000	2.54	1.10	2.29	0.014	159	0.0077
5	1.6	8.7	276,000	3.55	1.54	3.20	0.013	159	0.0075
6	1.9	10.2	324,000	4.75	2.06	4.28	0.013	160	0.0074
7	2.2	11.8*	373,000	6.15	2.67	5.54	0.013	160	0.0073
8	2.5	13.3*	422,000	7.67	3.33	6.91	0.013	161	0.0072
9	2.8	14.8*	470,000	9.33	4.04	8.40	0.012	161	0.0072
10	3.1	16.4*	518,000	11.20	4.85	10.09	0.012	161	0.0071
11	3.3	17.8*	564,000	13.10	5.68	11.80	0.012	161	0.0071
12	3.6	19.3*	613,000	15.20	6.60	13.69	0.012	161	0.0070
13	2.0	10.5*	332,000	4.98	2.16	4.48	0.013	160	0.0074

Notes:

1. Length of pipe tested: 111.05 feet
2. Date of calibration: 29-Mar-2022
3. Data: water temperature 45°F, unit weight 62.2 pcf, kinematic viscosity 1.54 x 10^{-5} ft^2/sec

*These test runs use velocities that exceed typical designs of municipal pipelines

TABLE 5: TEST RESULTS FOR 12-INCH PVC PIPE									
Run No.	**Flow Volume (cfs)**	**Flow Velocity (fps)**	**Inlet Reynolds Number**	**Friction Loss (ft of H_2O)**	**Friction Loss (psi)**	**Hydraulic Slope (ft/100 ft)**	**Darcy "f"**	**Hazen-Williams "C"**	**Manning's "n"**
1	1.5	2.0	126,000	0.23	0.10	0.10	0.017	150	0.0094
2	2.5	3.4	217,000	0.59	0.26	0.27	0.015	153	0.0089
3	3.5	4.8	304,000	1.10	0.48	0.50	0.014	154	0.0086
4	4.5	6.1	393,000	1.75	0.76	0.79	0.013	155	0.0084
5	5.7	7.7	493,000	2.66	1.15	1.21	0.013	155	0.0082
6	6.7	9.1	581,000	3.57	1.55	1.62	0.012	156	0.0081
7	7.9	10.6	679,000	4.74	2.06	2.15	0.012	156	0.0080
8	8.8	11.9*	761,000	5.83	2.53	2.65	0.012	157	0.0079
9	10.0	13.5*	861,000	7.30	3.16	3.31	0.012	157	0.0078
10	10.9	14.7*	943,000	8.64	3.75	3.92	0.011	157	0.0078
11	12.0	16.3*	1,040,000	10.40	4.49	4.72	0.011	157	0.0078
12	13.5	18.2*	1,170,000	12.80	5.55	5.81	0.011	157	0.0077

Notes:

1. Length of pipe tested: 220.29 feet
2. Date of calibration: 28-Mar-2022
3. Data: water temperature 46°F, unit weight 62.2 pcf, kinematic viscosity 1.52 x 10^{-5} ft^2/sec

*These test runs use velocities that exceed typical designs of municipal pipelines

Summary of Test Results

- Hazen-Williams "C" factor — average value was 159 for 6-inch pipe and 155 for 12-inch
- Manning's "n" number — average value was 0.0075 for 6-inch pipe and 0.0082 for 12-inch
- Darcy-Weisbach "f" factor — values ranged from 0.012 to 0.017 for 6-inch pipe and 0.011 to 0.017 for 12-inch

In all cases, results obtained verified the traditional values used for the last 40+ years for PVC pipe hydraulic design. The results also confirmed that these values are conservative.

FIELD TESTING

Introduction

To corroborate the results of the laboratory testing described, field tests were performed by M.E. Simpson in November 2022 at West Valley City, UT. The tests were run to determine Hazen-Williams "C" for installed 8-inch PVC pressure pipe. The pipe section that was chosen for testing had been in service in the Granger-Hunter Improvement District since 1976 (in service for 46 years). The field tests were witnessed by Research Professor Steven Barfuss, who had overseen the laboratory tests described. Oversight included planning, equipment validation, and test execution.

Process

The method for determining flow coefficients is as follows:

- Flow volumes are measured
- Pressure loss is measured between two hydrants spaced at a known distance apart
- Using the pressure, flow, and length values, Hazen-Williams "C" is calculated

Preparation for the tests included:

- Selection of an appropriate site
- Installation of pressure tubing and pressure instrumentation
- Installation of flow-measurement instrumentation
- Closure of valves and shut-off of residential connections

Test procedures included:

- Continuous measurement of differential pressures
- Continuous measurement of fluid flow

FIGURE 2: DIFFERENTIAL-PRESSURE INSTRUMENTATION

FIGURE 3: FLOW DISCHARGE THROUGH HOSE MONSTER

Pipe Dimensions

A run of 8-inch PVC pipe between two hydrants was used. Distance between the hydrants was 278 feet. Pipe dimensional information is found in Table 6.

TABLE 6: DIMENSIONS FOR 8-INCH PVC PIPE					
Section	ID 1 (in)	ID 2 (in)	ID 3 (in)	Average ID (in)	Pipe Length (ft)
1	8.0350	8.0005	7.9960	8.01	278
			Overall Average ID (in)	8.01	
			Average Flow Area (in^2)	50.40	
			Average Flow Area (ft^2)	0.35	

Results

Two tests were performed on the same length of pipe. Each test used a different flow velocity to generate additional data. Test information is found in Table 7.

TABLE 7: DIMENSIONS FOR 8-INCH PVC PIPE					
Run No.	Flow Volume (gpm)	Flow Velocity (fps)	Friction Loss (ft of H_2O)	Friction Loss (ft H_2O / ft)	Hazen-Williams "C"
1	606	3.86	1.30	0.005	164.2
2	1,370	8.73	5.93	0.021	163.3
				Average	163.8

Summary of Test Results

- The first test used a velocity of 3.86 fps — HW "C" factor was 164.2
- The second test used a velocity of 8.73 fps — HW "C" factor was 163.3
- Average HW "C" factor for the two tests was 163.8, about 9% higher than the recommended design of 150

FIGURE 4. EXCAVATED SAMPLES OF PVC WATER MAINS FOR DIMENSION MEASUREMENT

CONCLUSION: PVC PIPE FLOW COEFFICIENTS ARE CONSERVATIVE

The two questions addressed by hydraulics testing were answered:

- Results of hydraulic testing performed in the 1970s are verified
- Conservatism of recommended flow coefficients was confirmed. Tests showed that:
  - Hazen-Williams “C” = 150 is conservative for pressure pipe design
  - Manning’s “n” = 0.009 is conservative for gravity sewer pipe design

Designers of PVC piping systems can be confident that these coefficients have provided conservative hydraulic designs in the past and will continue to do so in the future. There is no need to design with a higher-friction PVC coefficient. The testing shows that even with varying flow rates and long use, the HW “C” factor remains above 150 and the Manning’s “n” stays below 0.009. The use of higher-friction coefficients results in engineering designs that are not consistent with previous and current findings of PVC pipe’s hydraulic attributes and may result in adding unnecessary project and operational costs. This is shown in the following section.

COMPARISON OF FLOW COEFFICIENTS: RECOMMENDED VS. CONSERVATIVE

This section provides examples of how the use of overly conservative hydraulic values (i.e., “C” = 120 or “n” = 0.013) may lead to additional costs for projects and pipeline operation (i.e., increase in pipe size, pumping costs, gravity pipe slope, etc.). Actual cost information of pipe sizes is not included.

PVC Water Main Example

Assume a PVC DR 18 watermain design requires sizing the pipe for a flow of 1,300 gpm while not exceeding a headloss of 10 feet per 1,000 feet of pipe. For:

- HW “C” factor of 120: 12” PVC DR 18 would be selected
- HW “C” factor of 150: 8” PVC DR 18 would be selected

PVC Transmission Main Example

Assume 20,000 feet of 24” PVC DR 25 pipe conveys 5,000 gpm, the pump has an overall efficiency of 75% while operating 24 hours/day, and the cost of electricity is $0.10/kWh. The pumping cost per year (not including inflation) based on friction loss is as follows:

- HW “C” factor of 120 represents $49,900/year
- HW “C” factor of 150 represents $33,200/year

PVC Gravity Sewer Main Example

Assume a PVC PS 46 sewer pipe design requires sizing the pipe for a flow of 14 cfs on a slope of 0.05 feet per 100 feet and maintaining a minimum velocity of 2 fps. For:

- Manning’s “n” of 0.013: 36” PVC PS 46 would be selected
- Manning’s “n” of 0.009: 30” PVC PS 46 would be selected

THE IMPORTANCE OF USING CONSERVATIVE FRICTION FACTORS WHEN COMPARING TO OTHER PIPE MATERIALS

Designers should realize that recommended PVC pipe Hazen-Williams “C” = 150 and Manning’s “n” = 0.009 are conservative values compared to test data. In fact, despite using a wide range of flow velocities, every data point in recent research has been at or better than these recommended values. When making comparisons with other materials, it is important to avoid using average values for friction factors for hydraulic design, since average values are not conservative. Users are encouraged to review test data from other pipe materials to understand how their recommended values were obtained. Additionally, it is essential that recommended industry coefficients include any internal pipe-wall or pipe-lining degradation.

ACKNOWLEDGEMENTS

The PVC Pipe Association expresses its appreciation to the Granger-Hunter Improvement District for allowing hydraulic testing to occur in their water system and also to their employees who actively assisted in making the tests happen.

Uni-Bell PVC Pipe Association

The PVC Pipe Association is the North American trade association for gasketed PVC pipe. Since 1971, PVCPA has been the authoritative source for information on PVC water, sewer, and reclaimed water pipe. The Association serves the engineering, regulatory, public health, and standardization communities.

Utah Water Research Laboratory

The Utah Water Resources Laboratory is an internationally renowned research institution at Utah State University. Dedicated in 1965, it is the oldest and one of the largest water research laboratories in the United States. The facility includes more than 113,000 square feet of office and laboratory space. UWRL is primarily focused on research in water and irrigation engineering and supports undergraduate and graduate programs in several subject areas.

M.E. Simpson Co., Inc.

M.E. Simpson was founded by Marvin Simpson in 1979 with the objective of providing technical services to water utilities throughout the Midwest. Since then, the company has improved distribution system performance for utilities, optimized distribution system data, and increased revenues for water systems throughout the United States.

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